Emergency Telemetry Performance

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Often an emergency telemetry mode is automatically selected by a spacecraft during emergencies. During such emergencies the DSN must acquire the spacecraft telemetry as rapidly as possible under weak fluctuating signal conditions. Test data herein show the bit error properties of one emergency telemetry mode candidate with a very low bit rate of 4 BPS. Analysis reveals the E_b/N_0 necessary to obtain the performance BER threshold and associated acquisition times.

I. Introduction

Receiving telemetry during a spacecraft emergency is far from optimal. The spacecraft may be experiencing an RF power failure or loss of antenna point under dynamic conditions to produce weak intermittent downlink RF and telemetry signals.

Such a problem was presented in support of the NASA ISPM mission design. The search for a low bit rate to increase the chances of receiving emergency telemetry began, and telemetry tests were performed to demonstrate the capability of the DSN to support 3.93 BPS, coded and uncoded. Coding options include Reed-Solomon (255,223) outer code concatenated with a convolutional (7, 1/2, 3) inner code. The uncoded case is a contender since acquisition is more rapid.

The objectives of the tests reported herein are to examine the BER performance and signal acquisition time for both coded and uncoded links around the specified BER threshold of 10^{-3}. The input E_b/N_0 needed for the threshold is to be established.

II. Test Configuration and Test Techniques

All tests were performed in Compatibility Test Area 21 (CTA-21) at JPL. A block diagram of the test setup is depicted in Fig. 1. RF and telemetry subsystems include SCA, an S-band transmitter, a Block-III RF receiver, a Block-III SDA, SSA and MCD. The test configuration included the convolutional coding for portions of the tests and uncoded for the remaining. CTA-21 had no capability for Reed-Solomon coding-decoding; therefore, no concatenated code tests were performed. Modulation included biphase modulation of symbols upon a 40 kHz squarewave subcarrier. Then this spectrum is phase modulated at 37 degrees mod index upon the S-Band carrier. All SNR levels were set by the standard Y-Factor technique.

Two problems impede progress when running telemetry tests at very low bit rates and with efficient codes. The first is test time. Sufficient test time is needed to accrue enough bit errors (N_e) for a high confidence interval and accuracy. With a given bit error rate BER (P_e) and bit rate (R), test time may be calculated by the following relation:

$$T_e = \frac{N_e/P_e}{R \cdot 60} \text{ minutes}$$

To accrue 100 errors at a $P_e = 1 \times 10^{-3}$ takes 6 hours and 11 minutes at 4.49 BPS. This length of time represents a large expenditure of manpower and test area time. The difficulty in making test setups is compounded by the use of the efficient convolutional code. Efficient codes result in a very "steep" BER curve. If the E_b/N_0 is set too high, an insufficient number of errors occur and the BER result is inaccurate. If the E_b/N_0 is set too low the MCD will lose node synchronization.

When telemetry tests are performed at CTA-21, burst errors accumulate within high speed blocks. There are 960 bits per block. If the BER is plotted as the bit errors occur, as in Fig. 2, the BER will start high and approach the correct BER asymptotically. Not until about 108 errors (or 7 bursts averaging 15+ errors) have occurred does the BER approach within 30% (or 0.1 dB) of the asymptotic BER value. Further work is needed to develop this technique analytically and empirically. For the testing analysis, a goal of 100 errors was established in the planning phase but due to the logistics of scheduling the test area and making long test runs, this was not found to be practical.

Testing for the uncoded 4.0 BPS proceeded uneventfully except for the large amount of test time needed.

III. Interpretation of Test Data

Test data in Table 1 is presented graphically in Fig. 3. The convolutionally encoded telemetry test results are compared against Linkabit baseband simulation data, also plotted in Fig. 3, to obtain total modulation-demodulation loss. At the performance threshold of $P_e = 10^{-3}$ the total system loss is 4.0 dB. This is equivalent to a baseband performance of $E_b/N_0 = 3.0$ dB. Note that with Reed-Solomon concatenation the system would be essentially errorless at 3.0 dB.

For input E_b/N_0 levels less than 7.0 dB, the BER performance is erratic. Erratic performance is qualitatively described as momentary and/or permanent data inversion, loss of MCD node synchronization, and very large data bursts beyond the ability of the Reed-Solomon concatenation to correct.

The uncoded test results in Fig. 3 are extrapolated down to a BER of 10^{-3}, showing that an input E_b/N_0 of 9.2 dB is necessary to obtain threshold performance. Tests 1, 2, and 3 (of Table 1) experienced 59, 7, and 128 bit errors respectively. To estimate the range of accuracy for these tests about 100 bit errors are needed to obtain a 90% confidence interval of being

within ±0.1 dB. Approximately 10 points are needed for an 80% confidence to be within ±0.5 dB (Ref. 1). No adverse behavior of the uncoded BER performance was apparent even though the RF carrier tracking margin ranged from 3.6 dB to 5.6 dB, which is well into the cycle slip region. Uncoded system loss is shown to be about 2.4 dB when the BER test data are compared to the theoretical curve.

IV. Acquisition Behavior

Due to the nature of the spacecraft emergency mode, quick acquisition time may be more desirable than a low bit error rate. If the spacecraft has a weak fluctuating SNR level that occasionally exceeds threshold, the acquisition time should be short by comparison to the time above threshold.

The RF and telemetry string acquisition-time calculations are broken down by subsystems and recorded in Table 2. Notable is the large percentage of time needed for Block III SDA to acquire. Also, the Reed-Solomon frame sync requires a very large percentage of the total acquisition time.

RF acquisition times of 5 and 10 minutes were assumed for E_b/N_0 levels of 7.0 and 9.0 dB, respectively. SDA, SSA, and MCD acquisition times were calculated from the instructions given in the DSN-Flight Project Interface Design Handbook. Reed-Solomon acquisition time is based on acquiring a 10080-bit frame within a range between 1/2 frame to 4 frames at 3.93 BPS.

V. Summary

Table 3 summarizes the BER and acquisition performance with use of three coding schemes: uncoded, convolutional, and Reed-Solomon convolutional concatenation. The uncoded telemetry needs a 9.2 dB input E_b/N_0 level for threshold performance but has the least acquisition time: 28 minutes and 18 seconds. The next best performer is the convolutionally code telemetry, which requires an input E_b/N_0 of only 7.0 dB; but the acquisition time has increased to 1 hour and 49 minutes. The Reed-Solomon concatenation only adds acquisition time. Since the required BER performance of 10^{-3} is met and the MCD will not maintain lock below 7.0 dB, the added Reed-Solomon coding gain cannot be utilized to enhance threshold performance.

The total system modulation-demodulation loss for convolutionally encoded telemetry at 4.49 BPS is 4.0 dB. System loss for the uncoded 4.0 BPS is 2.4 dB. Noting that the carrier tracking margin is between 5.5 and 4.6 dB these losses appear reasonable.

A closing note should be made about the Block-IV SDA now in operation at DSS-14 and DSS-43. These advanced SDAs have third-order tracking loops which can significantly reduce acquisition time. No calculations have been submitted at this time; the question has been left open for a potential future effort.

Reference

1. Rollins, W. W., "Confidence Level in Bit Error Rate Measurement," *Telecommunication and Data*, December 1977.

Abbreviations

BER	bit error rate
BPS	bits per second
CTA-21	Compatibility Test Area-21 at JPL
dB	decibel
DSN	Deep Space Network
E_b/N_0	energy per bit per spectral noise density
ISPM	International Solar Polar Mission
JPL	Jet Propulsion Laboratory
kHz	kilohertz
MCD	maximum likelihood detector
P_e	probability of error
PN	pseudo noise
RF	radio frequency
R-S	Reed-Solomon code
SCA	simulation conversion assembly
SDA	subcarrier demodulation assembly
SNR	signal to noise ratio
SPT	system performance test
SSA	symbol synchronizer assembly

Table 1. Bit error rate tabulated test data

Test no.	Input E_b/N_0, dB	Bit rate, BPS	Coding	Bit error rate, P_e	No. of bits	System loss, dB	Carrier margin, dB
1	6.5	4.00	UC[a]	1.1×10^{-2}	52	2.4	4.6
	6.5	4.00	UC	1.1×10^{-2}	7	2.4	4.6
2	5.5	4.00	UC	2.2×10^{-2}	128	2.6	3.6
3	7.5	4.00	UC	5.0×10^{-3}	5	2.4	5.6
4	8.0	4.49	C[b]	1.2×10^{-4}	11	4.2	6.5
5	8.5	4.49	C	2.5×10^{-5}	94	4.2	7.0
6	7.0	4.49	C	1.0×10^{-3}	95	4.0	5.5

[a]UC = uncoded

[b] C = convolutional (7, 1/2, 3)

Table 2. Calculated threshold acquisition times for the RF and telemetry string

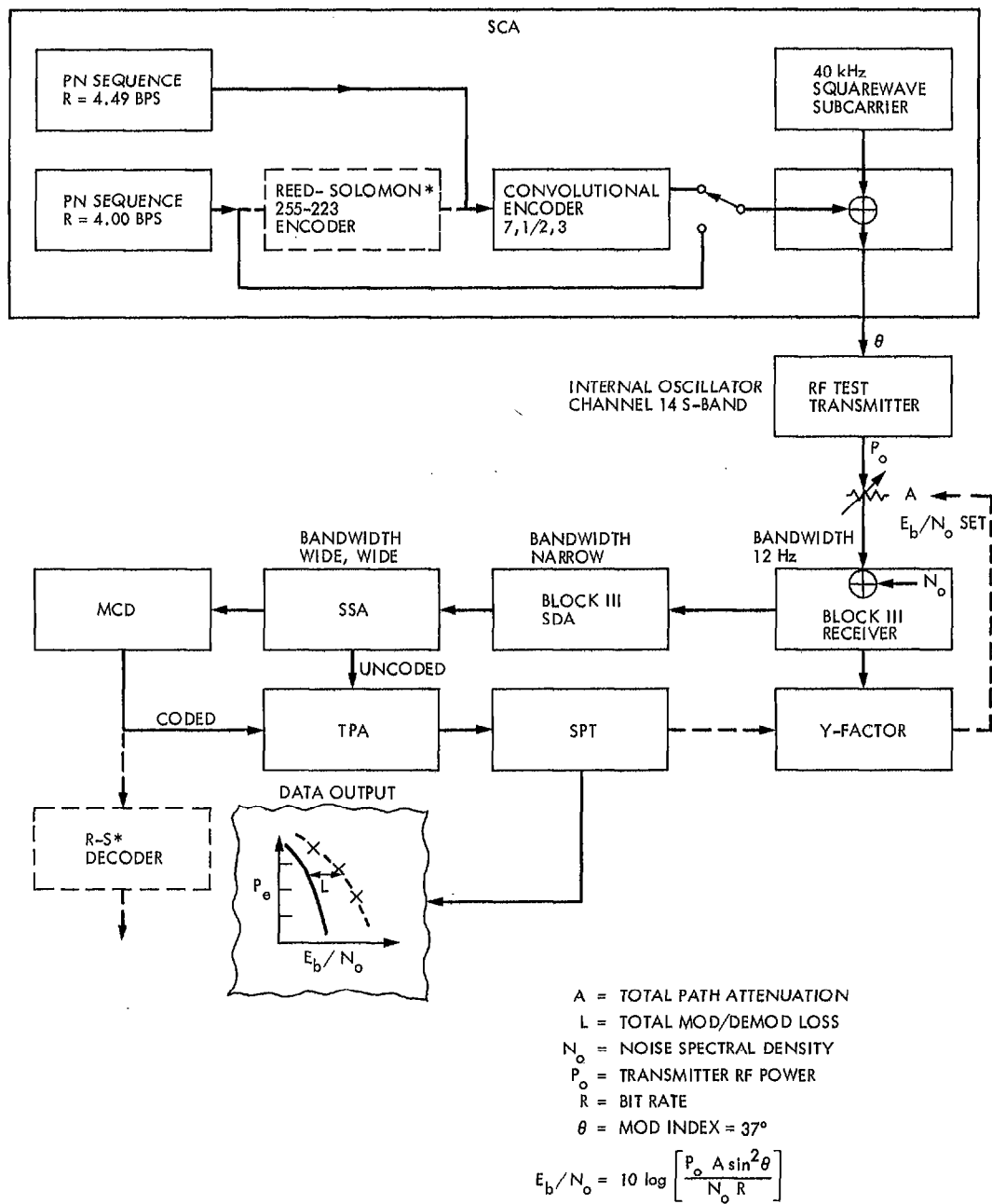| Subsystem	$E_b/N_0 = 7.0$ dB			$E_b/N_0 = 9.2$ dB		
	Uncoded	Coded		Uncoded	Coded	
RF (assumed)	00:10:00[a]	00:10:00	—	00:05:00	00:05:00	—
SDA	00:36:40	01:33:20	—	00:20:50	00:46:40	—
SSA	00:02:28	00:02:12	—	00:02:28	00:02:12	—
MCD	—	00:03:34	—	—	00:03:34	—
Subtotal			01:49:06			00:57:26
R-S (1/2 frame)	—	00:20:50	—	—	00:20:50	—
R-S (4 frames)	—	—	00:42:00	—	—	00:42:00
Total	00:49:08[b]	02:09:56	02:31:06	00:28:18	01:18:16	01:39:26

[a]Hours:minutes:seconds

[b]BER performance is above specified threshold $P_e > 10^{-3}$)

Table 3. Summary of acquisition time and BER performance for convolutionally coded and uncoded threshold E_b/N_0 input levels

Code conditions	$E_b/N_0 = 7.0$ dB		$E_b/N_0 = 9.2$ dB	
	Acquisition time	BER	Acquisition time	BER
Uncoded	00:49:08[a]	8×10^{-3}	00:28:18	1×10^{-3}
Convolutional	01:49:06	1×10^{-3}	00:57:26	7×10^{-6}
Concatenated Reed-Solomon and convolutional	02:09:56 to 02:31:06	"Errorless"	01:18:26 to 01:39:26	"Errorless"

[a]Hours:minutes:seconds

SCA

PN SEQUENCE
R = 4.49 BPS

PN SEQUENCE
R = 4.00 BPS

REED- SOLOMON *
255-223
ENCODER

CONVOLUTIONAL
ENCODER
7,1/2,3

40 kHz
SQUAREWAVE
SUBCARRIER

θ

INTERNAL OSCILLATOR
CHANNEL 14 S-BAND

RF TEST
TRANSMITTER

P_o

A

E_b/N_o SET

BANDWIDTH
WIDE, WIDE

BANDWIDTH
NARROW

BANDWIDTH
12 Hz

MCD

SSA

BLOCK III
SDA

N_o

BLOCK III
RECEIVER

UNCODED

CODED

TPA

SPT

Y-FACTOR

DATA OUTPUT

R-S*
DECODER

P_e

L

E_b/N_o

A = TOTAL PATH ATTENUATION
L = TOTAL MOD/DEMOD LOSS
N_o = NOISE SPECTRAL DENSITY
P_o = TRANSMITTER RF POWER
R = BIT RATE
θ = MOD INDEX = 37°

$$E_b/N_o = 10 \log \left[\frac{P_o \, A \sin^2\theta}{N_o \, R} \right]$$

*DUE TO PROGRAM RESTRICTION TO BIT RATES AT OR ABOVE 4 BPS, A BIT
RATE OF 4.0 BPS WAS USED TO APPROXIMATE THE BIT RATE OF 3.93 BPS.
CTA-21 HAS NO CAPABILITY FOR REED-SOLOMON

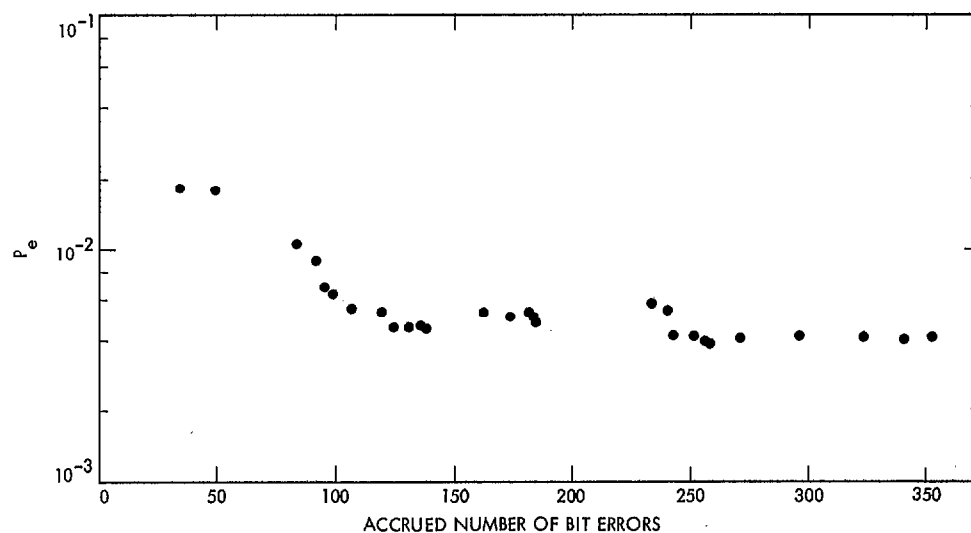**Fig. 1. Telemetry test configuration at CTA-21**

Fig. 2. Asymptotic behavior of accrued errors occurring in a high-speed block size of 960 bits, with input $E_b/N_0 = 6.5$ dB, $R = 4.49$ BPS, a convolutional code (7, 1/2, 3), and the carrier margin in $2 B_L = 5.5$ dB
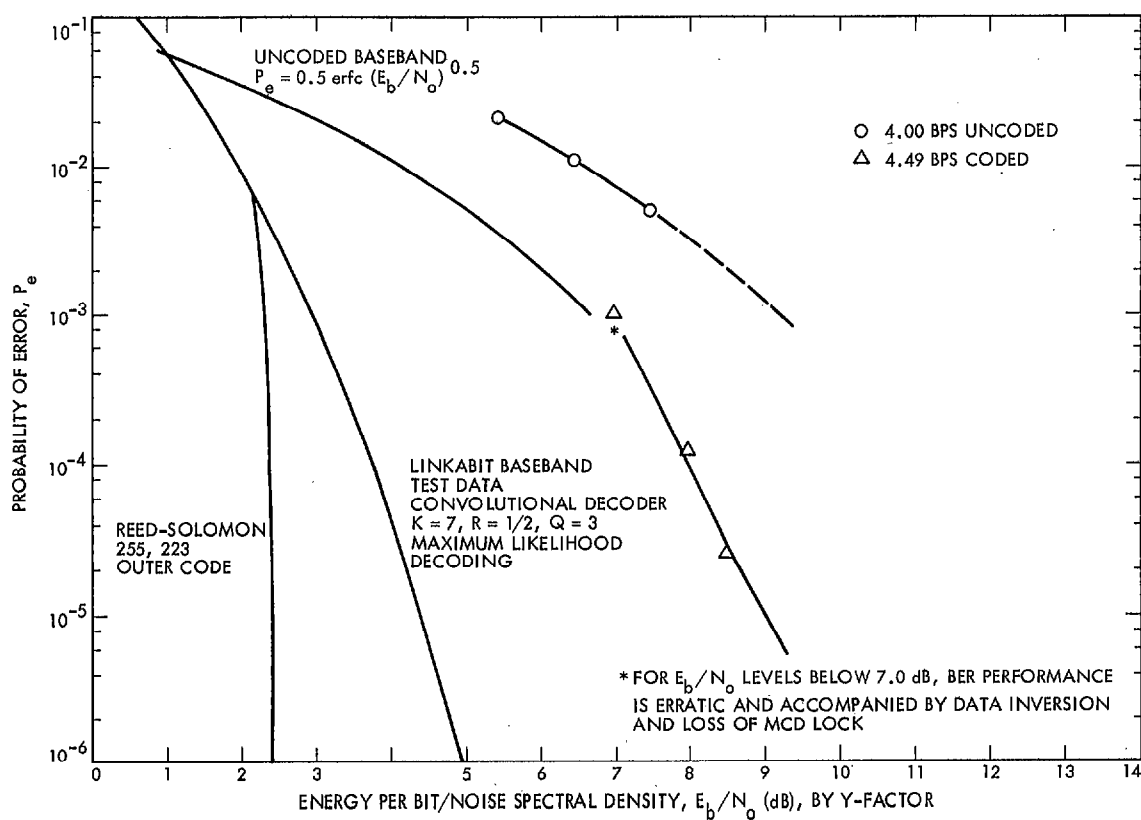

Fig. 3. NASA-ISPM emergency mode telemetry performance